Chapter 3
Standards and Specifications for Control Surveying Applications

3-1. General

This chapter details standards and specifications for control surveying applications and provides guidance on how to reach them.

3-2. Accuracy

a. This section prescribes field surveying standards and specifications that are applicable to surveys performed to provide base reference control, regardless of the application, whether in support of the engineering design, planning, construction, project operation and maintenance, real estate, and/or regulatory enforcement functions.

NOTE: The accuracy of control surveying measurements should be consistent with the purpose of the survey. When evaluating the technique to be used and accuracies desired, the surveyor must evaluate the limits of the errors of the equipment involved, the procedures to be followed, and the error propagation. These evaluations should be firmly based on past experience or written guidance. It is important to remember in this evaluation that the best survey is the one that provides the data at the required accuracy levels without wasting manpower, time, and money.

b. Survey accuracy standards prescribed in this section relate to the relative accuracy derived from a particular survey. This relative accuracy (or precision) is estimated by internal closure checks of the survey run through the local project, map, or construction site. Relative survey accuracy estimates are traditionally expressed as ratios of the misclosure to the total length of the survey (e.g., 1:10,000). Relative survey accuracies are different than map accuracies, which are expressed in terms of limiting positional error. Since map compilation is dependent on survey control, map accuracies will ultimately hinge on the adequacy and accuracy of the base survey used to control the map.

c. Tables 3-1 and 3-2 detail the basic minimum criteria required for planning, performing, and evaluating the adequacy of control surveys.

d. These criteria apply to all conventional control surveying and GPS surveying activities regardless of the intended accuracies.

e. Many of the criteria shown in the tables are developed from FGCS standards for performing conventional control surveys and GPS surveys. The criteria listed in the tables have been modified to provide more practical standards for engineering and survey densification. FGCS Standards and Specifications for Geodetic Control Networks covers all aspects of performing conventional control surveys for high-precision geodetic network densification purposes, while FGCS GPS Standards covers the use of GPS surveys for the same application. This intended application of techniques is not practical for typical civil works, military construction, and environmental restoration activities where lower precision control is acceptable.

f. If a primary function of a survey is to support NGRS densification, then specifications listed in the FGCS publications (1984 and 1988) should be followed in lieu of those in Tables 3-1 and 3-2.

(1) Survey classification. A survey shall be classified based on its horizontal point closure ratio, as indicated in Table 3-1 or the vertical elevation difference closure standard given in Table 3-2.

Table 3-1
USACE Point Closure Standards for Horizontal Control Surveys

USACE Classification	Point Closure Standard (Ratio)
Second Order Class I	1:50,000
Second Order Class II	1:20,000
Third Order Class I	1:10,000
Third Order Class II	1: 5,000
Construction Layout/ Fourth Order	1:2,500 - 1:20,000

Table 3-2
USACE Point Closure Standards for Vertical Control Surveys

USACE Classiciation	Point Closure Standard (Feet)
Second Order Class I	$0.025*M^{0.5}$
Second Order Class II	$0.035*M^{0.5}$
Third Order	$0.050*M^{0.5}$
Construction Layout/Fourth Order	$0.100*M^{0.5}$

NOTE: $M^{0.5}$ = square root of distance M in miles

(2) Horizontal control standards. The horizontal point closure is determined by dividing the linear distance misclosure of the survey into the overall circuit length of a traverse, loop, or network line/circuit. When independent directions or angles are observed, as on a conventional survey (i.e., traverse, trilateration, or triangulation), these angular misclosures may optionally be distributed before assessing positional misclosure. In cases where GPS vectors are measured in geocentric coordinates, then the three-dimensional positional misclosure is assessed.

(a) Approximate surveying. Approximate surveying work should be classified based on the survey's estimated or observed positional errors. This would include absolute GPS and some differential GPS techniques with positional accuracies ranging from 10 to 150 feet (2DRMS). There is no order classification for such approximate work.

(b) Higher order survey. Requirements for relative line accuracies exceeding 1:50,000 are rare for most USACE applications. Surveys requiring accuracies of First-Order (1:100,000) or better should be performed using FGCS standards and specifications, and must be adjusted by the NGS.

(c) Construction layout or grade control. The Construction Layout or Grade Control USACE Classification is analogous to traditional Fourth-Order work. This classification is intended to cover temporary control used for alignment, grading, and measurement of various types of construction, and some local site plan topographic mapping or photo mapping control work. Accuracy standards will vary with the type of construction. Lower accuracies (1:2,500 - 1:5,000) are acceptable for earthwork, embankment, beach fill, and levee alignment stakeout and grading, and some site plan, curb and gutter, utility building foundation, sidewalk, and small roadway stakeout. Moderate accuracies (1:5,000) are used in most pipeline, sewer, culvert, catch basin, and manhole stakeout, and for general residential building foundation and footing construction, major highway pavement, and concrete runway stakeout work. Somewhat higher accuracies (1:10,000 - 1:20,000) are used for aligning longer bridge spans, tunnels, and large commercial structures. For extensive bridge or tunnel projects, 1:50,000 or even 1:100,000 relative accuracy alignment work may be required. Vertical grade is usually observed to the nearest 0.01 foot for most construction work, although 0.1-foot accuracy is sufficient for riprap placement, grading, and small diameter pipe placement. Construction control points are typically marked by semi-permanent or temporary monuments (e.g., plastic hubs, P-K nails, wooden grade stakes). Control may be established by short, non-redundant spur shots, using total stations or GPS, or by single traverse runs between two existing permanent control points. Positional accuracy will be commensurate with, and relative to, that of the existing point(s) from which the new point is established.

(3) Vertical control standards. The vertical accuracy of a survey is determined by the elevation misclosure within a level section or level loop. For conventional differential or trigonometric leveling, section or loop misclosures (in feet) shall not exceed the limits shown in Table 3-2, where the line or circuit length (M) is measured in miles. Fourth-Order accuracies are intended for construction layout grading work. Procedural specifications or restrictions pertaining to vertical control surveying methods or equipment should not be overly restrictive.

(4) Contract compliance with USACE survey standards. Contract compliance assessment shall be based on the prescribed point closure standards of internal loops, not on closure with external networks of unknown accuracy. In cases where internal loops are not observed, then assessment must be based on external closures. Specified closure accuracy standards shall not be specified that exceed those required for the project, regardless of the accuracy capabilities of the survey equipment.

3-3. General Procedural Standards and Specifications

a. Most survey applications in typical civil works and military arenas can be satisfied with a Second- or Third-Order level of accuracy. Higher levels of accuracy are required for the densification of high precision geodetic networks and some forms of deformation monitoring.

b. Since most modern survey equipment (e.g., GPS or electronic total stations) are capable of achieving far higher accuracies than those required for engineering, construction, and mapping, only generalized field survey specifications are necessary for most USACE work. The following paragraphs outline some of the more critical specifications which relate to the USACE horizontal and vertical standards. Additional guidance for performing control surveying is found in subsequent chapters, as well as many of the technical manuals listed in Appendix A.

(1) Survey instrumentation criteria. USACE Commands shall minimize the use of rigid requirements for particular surveying equipment or instruments used by professional surveying contractors. In some instances,

contract technical specifications may prescribe a general type of instrument system be employed (e.g., total station, GPS, spirit level), along with any unique operating or calibration requirements.

(2) Survey geometry and field observing criteria. In lieu of providing detailed government procedural specifications, professional contractors may be presumed capable of performing surveys in accordance with accepted industry standards and practices. Any geometrical form of survey network may be formed: traverses, loops, networks, and cross-links within networks. Traverses should generally be closed back (or looped) to the same point, to allow an assessment of the internal misclosure accuracies. Survey alignment, orientation, and observing criteria should not be rigidly specified; however, guidance regarding limits on numbers of traverse stations, minimum traverse course lengths, auxiliary connections, etc. are provided in the subsequent chapters of this EM, as well in other EM's listed in Appendix A.

(3) Connections to existing control. USACE surveys should be connected to existing local control or project control monuments/benchmarks. These existing points may be those of any Federal (including USACE project control), state, local, or private agency. Ties to local USACE project control and boundary monuments are absolutely essential and critical to design, construction, and real estate. In order to minimize scale or orientation errors, at least two existing monuments should be connected, if practicable. However, survey quality control accuracy assessments (Tables 3-1 and 3-2) shall be based on internal traverse or level line closures--not on external closures between or with existing monuments or benchmarks. Accuracy assessments based on external closures typically require a knowledge of the statistical variances in the fixed network.

(4) Connections to NGRS control. The NGRS pertains to geodetic control monuments with coordinate or elevation data published by the NGS. It is recommended that USACE surveys be connected with one or more stations on the NGRS when practicable and feasible. Connections with the NGRS shall be subordinate to the requirements for connections with local/project control. Connections with local/project control that has previously been connected to the NGRS are adequate in most cases.

(5) Survey datums. A variety of survey datums and references are used throughout USACE projects. It is recommended that horizontal surveys be referenced to either the North American Datum of 1983 (NAD 83) or NAD 27 systems, with coordinates referred to the local SPCS for the area. The Universal Transverse Mercator (UTM) grid system may be used for military operational or tactical uses, in OCONUS locales without a local coordinate system, or on some civil projects crossing multiple SPCS zones. Vertical control should be referenced to either the National Geodetic Vertical Datum, 1929 Adjustment (NGVD 29) or the North American Vertical Datum, 1988 Adjustment (NAVD 88). Independent survey datums and reference systems shall be avoided unless required by local code, statute, or practice. This includes local tangent grid systems, state High Accuracy Reference Networks (HARN), and unreferenced construction baseline station-offset control.

(6) Spur points. Spur points (open-ended traverses or level lines) should be avoided to the maximum extent practicable. In many cases, it is acceptable survey procedure for temporary Fourth-Order construction control, provided adequate blunder detection is taken. Kinematic differential GPS (DGPS code or carrier phase tracking) surveys are effectively spur point surveys with relative accuracies well in excess of Third-Order standards. These DGPS kinematic spur techniques may be acceptable procedures for most control surveying in the future, provided blunder protection procedures are developed. Refer to EM 1110-1-1003 for further GPS guidance.

(7) Survey adjustments. The standard adjustment method in USACE will be either the Compass Rule or Least Squares. Technical (and contractual) compliance with accuracy standards prescribed in Tables 3-1 and 3-2 will be based on the internal point misclosures. Propagated relative distance/line accuracy statistics used by FGCS that result from unconstrained (minimally constrained) least squares adjustment error propagation statistics may be assumed comparable to relative misclosure accuracy estimates for survey quality control assessment. Surveys may be adjusted (i.e., constrained) to existing control without regard to the variances in the existing network adjustment. Exceptions to this requirement are surveys performed to FGCS standards and specifications that are adjusted by NGS.

(8) Data recording and archiving. Field survey data may be recorded either manually or electronically. Manual recordation should follow industry practice, using formats outlined in various technical manuals (Appendix A). Refer to EM 1110-1-1005 for electronic survey data collection standards.

3-4. Construction Surveys

In-house and contracted construction surveys generally will be performed to meet Third-Order-Class II (1:5,000) accuracy. Some stake-out work for earthwork clearing and grading, and other purposes, may need only be performed to meet Fourth-Order accuracy requirements. Other stake-out work, such as tunnel or bridge pier alignment, may require Second-Order or higher accuracy criteria. Construction survey procedural specifications should follow recognized industry practices. Reference also FM 5-233, Construction Surveying.

3-5. Cadastral and Real Estate Surveys

Many state codes, rules, or statutes prescribe minimum technical standards for surveying and mapping. Generally, most state accuracy standards for real property surveys parallel USACE Third-Order point closure standards--usually ranging between 1:5,000 and 1:10,000. USACE and its contractors shall follow applicable state minimum technical standards for real property surveys involving the determination of the perimeters of a parcel or tract of land by establishing or reestablishing corners, monuments, and boundary lines, for the purpose of describing, locating fixed improvements, or platting or dividing parcels. Although state minimum standards relate primarily to accuracies of land and boundary surveys, other types of survey work may also be covered in some areas. See also ER 405-1-12, Real Estate Handbook. Reference also the standards and specifications prescribed in the "Manual of Instruction for the Survey of the Public Lands of the United States" (U.S. Bureau of Land Management 1947) for cadastral surveys, or surveys of private lands abutting or adjoining Government lands.

3-6. Geodetic Control Surveys

a. Geodetic control surveys are usually performed for the purpose of establishing a basic framework to be included in the national geodetic reference network, or NGRS. These geodetic survey functions are distinct from the survey procedures and standards defined in this EM which are intended to support USACE engineering, construction, mapping, and Geographic Information System (GIS) activities.

b. Geodetic control surveys of permanently monumented control points that are to be incorporated in the NGRS must be performed to far more rigorous standards and specifications than are surveys used for general engineering, construction, mapping, or cadastral purposes. When a project requires NGRS densification, or such densification is a desirable by-product and is economically justified, USACE Commands should conform to FGCS survey standards and specifications, and other criteria prescribed under Office of Management and Budget (OMB) Circular A-16 (OMB 1990). This includes related automated data recording, submittal, project review, and adjustment requirements mandated by FGCS and NGS. Details outlining the proposed use of FGCS standards and specifications in lieu of USACE standards, including specific requirements for connections to the NGRS, shall be included in the descriptions of survey and mapping activities contained in project authorization documents.

c. Geodetic control surveys intended for support to and inclusion in the NGRS must be done in accordance with the following FGCS publications:

(1) "Standards and Specifications for Geodetic Control Networks" (FGCS 1984).

(2) "Geometric Geodetic Accuracy Standards and Specifications for Using GPS Relative Positioning Techniques" (FGCS 1988).

(3) "Input Formats and Specifications of the National Geodetic Data Base" (also termed the "Bluebook") (FGCS 1980).

(4) "Guidelines for Submitting GPS Relative Positioning Data to the National Geodetic Survey" (NGS 1988).

A survey performed to FGCS accuracy standards and specifications cannot be definitively classified or certified until the NGS has performed a variance analysis of the survey relative to the existing NGRS. This analysis and certification cannot be performed by USACE Commands--only the NGS can perform this function. It is estimated that performing surveys to meet these FGCS standards, specifications, and archiving criteria can add between 25 and 50 percent to the surveying costs of a project. Therefore, sound judgment must be exercised on each project when determining the practicability of doing survey work that, in addition to meeting the needs of the project, can be used for support to and inclusion in the NGRS.

3-7. Topographic Site Plan Mapping Surveys

Control surveys from which site plan mapping is densified (using plane tables, electronic total stations, or GPS) are normally established to USACE Third-Order standards. Follow guidance in FM 5-233, Construction Surveying;

FM 5-82D, Topographic Surveyor; FM 5-232, Geodetic and Topographic Surveying; EM 1110-1-1005.

3-8. Structural Deformation Surveys

Structural deformation surveys are performed in compliance with the requirements in ER 1110-2-100, often termed PICES surveys. PICES surveys require high line vector and/or positional accuracies to monitor the relative movement of monoliths, walls, embankments, etc. PICES survey accuracy standards vary with the type of construction, structural stability, failure probability, and impact, etc. In general, horizontal and vertical deformation monitoring survey procedures are performed relative to a control network established for the structure. Ties to the NGRS or NGVD 29 are not necessary other than for general reference; and then only an USACE Third-Order connection is needed. FGCS geodetic relative accuracy standards are not applicable to these localized movement surveys. Other deformation survey and instrumentation specifications and procedures for earth and rock fill dams and concrete structures are in EM 1110-2-1908 and EM 1110-2-4300.

3-9. Photogrammetric Mapping Control Surveys

Control surveys required for controlling photogrammetric mapping products will normally be performed to USACE Third-Order standards. Occasionally USACE Second-Order standards will be required for extensive aerotriangulation work. Reference EM 1110-1-1000, for detailed photogrammetric mapping standards and specifications.

3-10. Hydrographic Surveys

Control points for USACE hydrographic surveys generally are set to Third-Order horizontal and vertical accuracy. Exceptions are noted in EM 1110-2-1003. Hydrographic depth sounding accuracies are based on the linear and radial error measures described in EM 1110-2-1003, as well as hydrographic survey procedural specifications. Requirements for compliance with EM 1110-2-1003 are contained in ER 1130-2-307.

3-11. GIS Surveys

GIS raster or vector features can be scaled or digitized from any existing map. Typically a standard USGS 1:24,000 quadrangle map is adequate given the accuracies needed between GIS data features, elements, or classifications. Relative or absolute GPS (i.e., 10- to 30-foot precision) survey techniques may be adequate to tie GIS features where no maps exist. Second- or Third-Order control networks are generally adequate for all subsequent engineering, construction, real estate, GIS, and/or Automated Mapping/Facilities Management (AM/FM) control.